STORY

Working document

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Use cases and Key Performance Indicators (KPIs) of the STORY project

Authors:
Andrej Gubina, Tomi Medved and Zupančič, Jernej (University of Ljubljana)
Raquel Garde, Gabriel García and Cecilio Sarobe (CENER)
Andreas Tuerk, Johanna Pucker, Camilla Neumann (Joanneum Research)

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1 Scope

This working document describes use cases and Key Performance Indicators (KPIs) defined within the STORY project. The document also outlines the methodology followed to identify and define the KPIs according to the aims to be analysed and/or tested in the STORY demonstration cases (i.e. demos).

The document collects both, the general KPIs, applicable to all demos, and specific KPIs, applicable to specific demos use cases of the STORY project, their definitions and calculation methods to monitor the performance of the demos and to provide the inputs for the simulations and analysis within WP7 Extrapolation and WP8 Business preconditions.

The general KPIs described in the document can be classified as technical, economic and environmental. We do not include the KPIs related to “stakeholder behaviour analysis” as we are applying a different methodology to define them that is described in the “Monitoring Strategies” document.

This document serves as a foundation and a guideline for the KPIs which should be considered. As the demo cases differ among themselves, so do the available data and therefore not all KPIs can be calculated in all demos. Due to the budget restrictions, no additional work or measurement beyond that needed to carry out the activities of the demo is required by any of the project partners.

2 The terminology

For better understanding, a short description of terminology is provided.

Term	Meaning
Control strategy	A series of decision-making steps involving algorithms and input/outputs that are needed to implement a use case
Functionality	A property of a device or of a system. It is a combination of technical properties and control algorithm. The functionalities are described in the control strategies chapter.
Use case	Description of the services and the required implementation of the control strategies to achieve the stated goals
Key performance indicator (KPI)	Quantity used to monitor the progress, either directly measurable or calculated from the measured data.

3 List of abbreviations

BC	Base case
CAES	compressed air energy storage
CS	Case study

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DRES	Distributed Renewable Energy Source
DSO	Distribution System Operator
GHG	Greenhouse Gas
HV	High voltage
KPI	Key Performance Indicator
LV	Low voltage
MV	Medium voltage
OHL	Oud Heverlee (location)
OLTC	On Line Tap Changer
PCC	Point of Common Coupling
SCL	Self-consumption level
SSL	Self-sufficiency level
SOC	State of charge

4 List of STORY demos

Demo 1: Oud Heverlee, Belgium a) Living Lab and b) four other buildings with flexible devices
Demo 2: Oud Heverlee, Belgium a) Local Energy Community and b) flexible neighbourhood that interacts with the grid/with the market
Demo 3: Storage in the EXCAL factory in Spain
Demo 4: ORC at the Beneens factory site, Belgium
Demo 5: CAES in Lecale, Northern Ireland
Demo 6: Community battery a) in the village of Suha and b) the headquarters of Elektro Gorenjska

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7 Performance Indicators (KPIs) Overview

The simulation and demonstration activities performed in the STORY project aim to achieve the use cases of the project. The use cases are related to the general aims that we want to achieve in demonstrations, aligned with the STORY's main goals. To evaluate the quality of our performance and to assess the efficiency of the control strategies taken, an evaluation methodology based on KPIs was designed, where for each KPI a baseline and its range (upper, lower limit and optimal level) is defined.

Each of the use cases can be achieved by different control strategies, which differ in costs and side effects. To assess all the control strategies' different impacts, we apply three main types of KPIs:

- Technical KPIs, including grid-related and device-level KPIs
- Environmental KPIs, and
- Economic KPIs.

To assess the success of the control strategies through the results of the KPIs, the control strategies need to be compared to baseline criteria, specific to each KPI. The determination of the baseline criteria will be presented in the separate report. The KPI assessment methodology flowchart is presented in Figure 1.

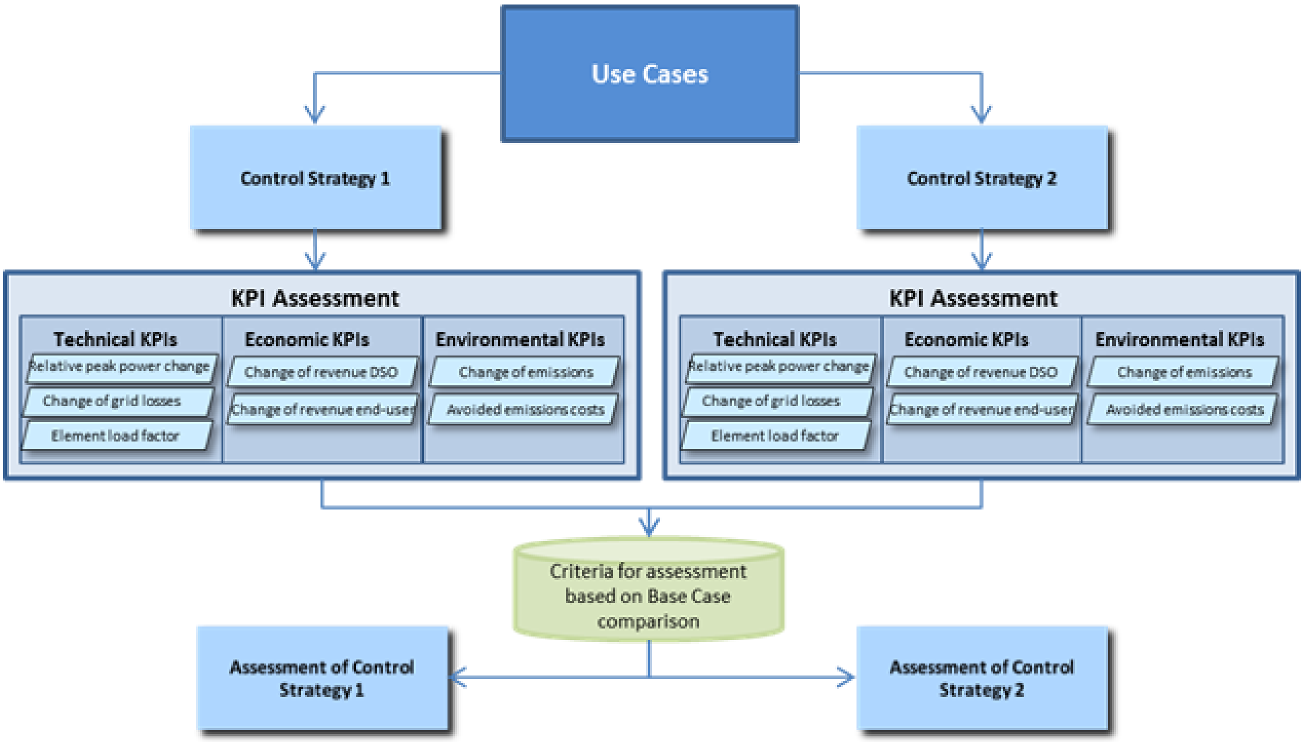

Figure 1: The methodology of comparing efficiency of control strategies

In STORY the use cases will be demo-tested and simulated, but not all use cases can be both, demo tested and simulated as some of them are limited only to simulations, e.g. Zero load provision (islanding mode) due to demo site limitations. Testing of some others is possible only

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in real demo cases (e.g. reserve provision), as shown in Tab. 3.1. In this report, a mark D for demonstration, S for simulation or both are written next to each use case.

Table 1: The level of testing of the KPIs in STORY

Use case	Simulation	Demonstration
Increased RES use		
Increased self-consumption		
Electrical peak shifting / Peak shaving		
Peak power reduction of heat demand		
Reserve provision		
Zero load provision		
Voltage control		
Reactive power compensation		
Local optimization of households and neighbourhoods		
Service optimization (system level value)		
Heat loss reduction of district heating network by multi-temperature network		
Load and generation on demand for the CAES		

The use cases can be met using different control strategies. In STORY we focus only on the control strategies involving energy storage implementation and control, except for flexible demand control in some of the demos. The control strategies can involve either electricity, heat or a combination of both.

The control strategies used to achieve the goals or use cases have different effects on the network operation, environment, and economics of the system. Thus, each measure needs to be evaluated with all three types of KPIs. We can highlight the primary effect intended with the proposed control strategy and the specific KPI to assess the performance of the control strategy. However, to see the overall picture and the possible effects on some other fields, each of the control strategies must be evaluated with the whole set of general KPIs. As the demos differ in use cases and in the technology implemented, not all KPIs can be calculated in each of them due to the missing measured quantities or due to other technical reasons. Therefore, in each demo, we only assess the KPIs that can be calculated with the available data without additional cost or workload for the demo leaders.

In addition to the general KPIs, applicable to all demos, specific KPIs are used to evaluate technology-specific characteristics and performance of the demos. They need to be modified specifically for each technology in those demos and adapted to their functionalities. The table below gives an overview of the KPI categories.

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Table 2: An overview of the KPI categories in STORY

	KPI Category	Description
	Technical KPIs	• Grid-related KPIs • Device-level KPIs
	Economic KPIs	• Change of revenue for the main actors
	Environmental KPIs	• Change of emissions • Avoided emissions costs

8 Description of the STORY use cases

The use cases are the goals of a demo that are aligned with the goals of the project. They are reflected in the use cases that describe the real world application of the goals that we want to achieve by implementing new solutions. The use cases listed below are aligned with the goals of the STORY project in general and demo cases in particular as well as simulations that need to be carried out in STORY. The first two use cases relate to all demos as they are based on the overarching aims of the project.

8.1 Increased self-consumption (D + S)

Increased self-consumption involves increasing the contribution of local generation to the total load supply, reducing thereby the energy supply from the grid. This service can be provided by avoiding the curtailment or export of surplus onsite energy generation, either by locally storing energy for a later use or following a demand-response strategy. This use case is analysed in all demo cases which have on-site generation.

8.2 Increased RES use (D+S)

An increased RES use refers to the maximisation of the load supplied by the present renewable energy sources, either instantaneously by means of a demand response strategy or shifting energy by the means of an energy storage device. The goal of increased RES use cases is to maximise the consumed RES production avoiding reductions/curtailment.

8.3 Electrical peak shifting / Peak shaving (D+S)

Traditionally, electrical peak shifting/peak shaving is a demand response strategy of controlling the maximum consumption of the local grid. In STORY, electricity storage is added in addition to the responsive demand. The ultimate goal of peak shaving is to change the energy pattern in the local grid in order to reduce peak consumption. This allows the DSO to avoid /postpone grid

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capacity expansion and other investors to avoid generation capacity installation to supply the peaks of a highly variable load.

- Peak shaving involves reducing the load supplied from the central grid in peak hours by local energy supply thus reducing the peak demand on the grid.
- Peak shifting involves shifting of energy consumption in time by reducing the amount of energy consumed during the peak demand hours and increasing it in off-peak times.

In STORY this use case is also analysed from the generation side. Due to the emerging PV generation capacity in the LV distribution network, the peaks in production are causing increasingly more problems with overvoltage during the day and undervoltage in the evening and at night. The goal is to reduce the PV generation peaks with activating energy storage (batteries) or with controlling flexible load.

This use case is addressed in the OH building and neighbourhood level, the Spanish factory and the Slovenian (Suha and Kranj) demos.

8.4 Peak power reduction of heat demand (D)

Peak power reduction of the heat demand refers to the reduction of the thermal demand peak. It can be achieved by the integration of thermal energy storage and load shifting. During periods with low heat demand or high local generation the thermal energy storage system can be charged. During periods with high heat demand, heat can be supplied by heating installation and the thermal energy storage. Integration of thermal energy storage can reduce the cost of the heating installation as the latter can be dimensioned at base load instead of peak power. To control the heating installation, an accurate State of Charge (SoC) determination of the thermal energy storage system is important.

This use case is being analysed in OH 1&2 and the Beneens demo cases.

8.5 Reserve provision (D)

Reserve provision is the act of a power generation or consumption capacity made available to the system operator to increase or decrease electricity injection within a short interval of time to meet the demand in case of an outage event in its network. Different types of reserve can vary in scope, activation time and duration.

Due to the specific nature of the reserve provision, which is activated upon request by DSO or TSO, it will be tested through two STORY demonstrations:

- EG demo: to prove the viability of reserve provision by the battery in the LV network and
- Lecale demo: to test the compressed air energy storage (CAES) capabilities to provide various types of reserve.

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8.6 Zero load provision (S)

Zero load provision consists of obtaining a minimal power flow (ideally zero) through the transformer station or the Point of Common Coupling (PCC) by instantaneously supplying or absorbing energy as required.

This goal is being analysed in the EG demo cases (Suha and Kranj) to demonstrate the capability of storage to balance the power flows to minimise or avoid the energy exchange with the grid.

8.7 Voltage control (D+S)

Voltage control service refers to continuously maintaining the voltage profile within its network operation limits. The goal of voltage control is, on the one hand, to mitigate voltage problems created mostly by RES local energy injection and on the other hand to keep the voltage level in the prescribed network operation limits.

This use case is analysed in the Suha and Oud-Heverlee demo case.

8.8 Reactive power compensation (S)

Reactive power compensation refers to compensating the reactive power consumed by electrical motors, transformers etc. and involves supplying or absorbing reactive power within a consumer network to avoid an undesirable reactive power exchange with the grid.
The main benefits identified are:

- Improvement of the system power factor
- Reduction of network losses
- Avoiding penalty charges from utilities for excessive consumption of reactive power
- Reduction of costs and increased revenues for the customer
- Increased system capacity and saving cost on new installations
- Improved voltage regulation in the network
- Increased power availability

This use case will be analysed in the EG demo case.

8.9 Local optimization of households and neighbourhoods (D+S)

Household level optimisation
The main goal of local optimization, or better said household level optimization, is focused solely on local information of a single household with control algorithms for DR that take into account only household conditions and limitations. This is performed in demo OHL1 in the peak shaving case.

Neighbourhood-level optimisation
The neighbourhood level optimisation also looks at very local consideration such as peak load or increased self-consumption, but does not take household consideration into account. It tries

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to optimize those objectives by looking at the neighbourhood as a single entity, using only locally available information.

This is tested in the peak-shaving business case, performed at neighbourhood level in OHL 2.

8.10 Service optimization (system level value) (D+S)

Service optimization is based on the pooling of flexible assets into a virtual power plant. The resources are coordinated to answer specific system level needs (electricity prices, reserve, etc.). This means local constraints (at neighbourhood level) will no longer be the priority of the control algorithm. It is therefore very important to assess the local impact of the system level optimisation. The impact can be positive (positive correlation between system needs and local needs) as well as locally detrimental (when this correlation is negative).

This is performed in the dynamic pricing business case, performed at household level in OHL1 and at neighbourhood level in OHL2. In the household level optimisation a system level value such as a high price will tend to indirectly coordinate household consumption. The local level optimisation will thereby lead to positive/negative local, neighbourhood and system-level impact.

8.11 Use cases for the CAES (D)

There are several use case related to the CAES as reflected also in the demo specific KPIs.

Demand reduction

When CAES is compressing and therefore acting as a load on the system we become eligible for demand side reduction services that would be described in a service contract with a Demand Side Unit (DSU). In the event of a system requirement the trip signal to shut down the compressor comes from DSU and payment in respect of contract is triggered.

Standby generation

When CAES is compressing or idle we become eligible for standby generation through the capacity market. This arrangement would be described in a contract with System Operator Northern Ireland (SONI) and/or the DSU. In the event of a system requirement the start signal for the expander would be received and payment in respect of contract is triggered.

Peak lopping

Maximising the quantity of air stored on a daily basis at commencement of the peak lopping episode (4pm - 8pm). Generation during this period will be on a load following profile. This will maximise generation export at the highest market prices. Minimise the quantity of compressed air remaining at the end of the peak lopping episode so that the system is ready for night-time (off-peak) compression duty. This arrangement will be described in a Power Purchase Agreement with a public electricity supply company. The fossil fuel combustion savings and the emission savings will be calculated and recorded.

Generation on demand

In parallel with Peak Lopping above, the “generation on demand” service will be sold to the DNO so that thermal loading on the substation will be kept within design limits. This will allow the DNO to defer or avoid costly upgrading of the substation and 33kV circuits.

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This arrangement will be described in a Generation on Demand contract. The KPI will be measured by technical performance of the CAES control system to commence generation when called to do so by the DNO and by fulfilment of all of the commercial agreements in the Generation on Demand contract.

Load on demand

Load on demand to avoid reverse power flow at the substation and thereby reduce constrained wind and solar on the 11kv circuits. Load on demand also avoids curtailment of distant windfarms. Three revenue streams identified are:

- Constrained wind (local)
- Constrained solar (local)
- Curtailed wind (distant)

These arrangements will be described in a Load on Demand contract. The KPI will be measured by technical performance of the CAES control system to commence compression when called to do so by the DNO and by fulfilment of all of the commercial agreements in the Load on Demand contract with local and distant renewable generators (payments would be made on a per MWh basis).

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9 General-purpose KPIs

While the economic and environmental KPIs are applied in all demos the application of the technical KPIs depend on the specific demo. Yet, there are several general technical KPIs which are applied in more than one demo. In addition to these general KPI'S, demo-specific ones were designed.

9.1 General technical KPIs-Overview

Table 3: Application of the technical KPIs

KPIs	OHL 1		OHL 2		Excal	Beneens	Lecale	Suha	Kranj
	LL	others	LEC	FlexNH					
Increase RES use	✓	✓	✓	✓	✓	✓	✓	✓	✓
Increased Self consumption use	✓	✓	✓	✓	✓	✓	✓	✓	✓
Peak-to-average demand ratio		✓			✓			✓	✓
Relative peak power change					✓	✓		✓	✓
Grid losses change					✓			✓	✓
Grid energy consumption change			✓	✓	✓			✓	✓
Current and voltage total harmonic distortion change			✓	✓	✓			✓	✓
Voltage deviation change			✓	✓	✓			✓	✓
Full Cycle Equivalents of Storage					✓			✓	✓
Storage capacity factor					✓			✓	✓
Storage efficiency	✓	✓					✓	✓	✓
Device availability		✓						✓	✓

9.2 Increased RES use (K1)

Definition:
Increased RES use is the difference in energy production of the RES unit which is increased with activation of the storage assets, DR units or other measures.

Calculation:

$$\Delta E_{RES}[\%] = \frac{E_{CS} - E_{BC}}{E_{BC}} \cdot 100\%$$

$\Delta E_{RES}[\%]$	increased RES use
$E_{BC}[kWh]$	RES unit production in kWh in base case in the defined interval (24h)
$E_{CS}\ [kWh]$	RES unit production in kWh in demo case in the defined interval (24)

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9.3 Increased self-consumption (K2)

Definition:
Associated with the previously defined use case Increased RES use, this KPI measures the self-consumption of locally produced energy by the loads in the network and self-sufficiency level of local assets. This applies to electricity and heat.

Self-consumption level SCL is defined as a ratio between self-consumed (or local consumption) of locally produced energy and the total amount of locally produced energy, of which the surplus is injected into the main grid. Self-sufficiency level SSL is defined as a ratio between the consumption, covered by local production and the total consumption over a certain monitored interval.

Calculation:

$$SCL(\%) = \frac{E_{Local,Consumed}(T)}{E_{Local,Produced}(T)} \cdot 100\%$$

$SCL(\%)$	Self-consumption level
$E_{Local,Consumed}(T)$	Locally generated energy, which is used for consumption within the monitored sector in the defined time interval T in [kWh].
$E_{Local,Produced}(T)$	Total amount of locally produced energy [kWh] in defined interval T.

Calculation:

$$SSL(\%) = \frac{C_{Locally\ covered}(T)}{C_{Total}(T)} \cdot 100\%$$

$SSL(\%)$	Self-sufficiency level
$C_{Locally\ covered}(T)$	Consumption in the network [kWh] in the defined interval (24 hours), which is covered by local sources and
$C_{Total}(T)$	Total consumption [kWh] in interval T (24 hours) in the network.

Proposed time interval: 24 hours

9.4 Grid-related KPIs

The grid-related KPIs are calculated based on the same input parameters for each demo case and simulation and are therefore core KPIs for the technical performance assessment. There are some established KPIs (e.g. CAIDI, CAIFI, SAIDI, SAIFI) designed for assessing the security of grid operation, which deal with the number of service interruptions. However, they are mostly not suitable for assessing the impact of new technologies on the power quality on the distribution level. Therefore, a set of new KPIs for the STORY use cases and the associated control strategies has been designed.

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9.4.1 Change of peak-to-average demand ratio (K3)

Definition:
Change of peak to average demand ratio is defined as the ratio between the peak value of the demand profile and the average value of demand. Ratios before and after the implementation of storage are compared in order to provide the relative change of peak to average ratio.

This KPI has been selected to evaluate the techno-economic benefits linked to an improvement of the grid capacity. Generally, grids and reinforcement plans are sized according to the peak power demand in the nodes. Therefore, most of the time the networks are underused since the energy demand is on average 2/3 of the peak power. An increased capacity factor leads to a rise in the use of the grid and a reduction of the energy cost.

Calculation:

$$\Delta PAR_{Demand}(\%) = \frac{\left[(\frac{|P_p|}{\underline{P}})_{BC} - (\frac{|P_p|}{\underline{P}})_{CS} \right]}{(\frac{|P_p|}{\underline{P}})_{BC}} \cdot 100\%$$

$\Delta PAR_{Demand}(\%)$	Change of the peak-to-average demand ratio relating to the case study and the base case [%],
$\left(\frac{\lvert P_p\rvert}{\lvert \underline{P}\rvert}\right)_{BC}$	Ratio of peak power (P) over base case average demand, where $\lvert P_p\rvert$ represents peak power and $\lvert \underline{P}\rvert$ represents average demand in selected time interval [unitless]
$\left(\frac{\lvert P_p\rvert}{\lvert \underline{P}\rvert}\right)_{CS}$	Case study average demand and peak power (P) ratio, where $\lvert P_p\rvert$ represents peak power and $\lvert \underline{P}\rvert$ represents average demand in selected time interval [unitless].

Proposed time intervals:
24hours
7 days
1 month

9.4.2 Relative peak power change (K4)

Definition:
Relative peak power change is defined as the change of peak power flows in the network, before and after storage implementation, compared to peak power levels before the storage technology implementation. In addition to the relative peak power, we also measure the relative average peak power. This KPI is suited to be calculated for a feeder on the transformer level, or PCC with the rest of the network, if applicable.

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Calculation:

$$\Delta RPP(\%) = \frac{P_{BC} - P_{CS}}{P_{BC}} \cdot 100\%$$

$\Delta RPP(\%)$	Relative peak power change
P_{CS}	Grid peak power [kW] in the demo case and
P_{BC}	Grid peak power [kW] in the base case.

Proposed time interval:
24 hours
7 days
30 days

9.4.3 Grid losses change (K5)

Definition:
Change of grid losses is defined as the deviation of losses in the network before the storage implementation and after the implementation of storage. This KPI is suited to be calculated for a feeder on transformer level, with the rest of the network, if applicable. Due to a reduced power flow through the transformer, the electricity losses will be lower on the complete distribution power infeed line (the MV line and MV/LV transformer).

Calculation:

$$\Delta E_{loss}(\%) = \frac{E_{loss,BC} - E_{loss,CS}}{E_{loss,BC}} \cdot 100\%$$

$\Delta E(\%)$	Relative change of grid losses [%]
$E_{loss,BC}$	Losses through transformer prior to implementation of storage and control [kWh]
$E_{loss,CS}$	Losses in case study [kWh]

The transformer losses are calculated based on the transformer's current measurements and the distribution transformer specification (copper losses data).

$$E_{loss} = E_{pri} - E_{sec}$$

Proposed time interval:
24 hours
7 days
30 days

The KPI for the proposed time intervals calculated for equal/comparable sun radiation conditions.

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9.4.4 Grid energy consumption change (K6)

Definition:
The grid energy consumption change KPI compares the grid-injected energy before and after storage implementation. With this KPI, we monitor the energy exchanged between the monitored region/section and the rest of the distribution grid and the increase of renewables share in local energy supply.

Calculation:

$$\Delta E_{Grid}(\%) = \frac{\Delta E_{Grid,Use\ Case} - \Delta E_{Grid,Base\ Case}}{\Delta E_{Grid,Base\ Case}} * 100\%$$

Where

$\Delta E_{Grid}(\%)$ Relative change of grid-supplied energy [%],

$\Delta E_{Grid,Use\ Case}$ Energy supplied from the main grid after the implementation of storage [kWh]

$\Delta E_{Grid,Base\ Case}$ Energy supplied from the grid before implementation [kWh].

Proposed time interval:
24 hours
7 days
30 days

The KPI for the proposed time intervals should be calculated for equal/comparable sun radiation conditions.

9.4.5 Current and voltage total harmonic distortion change (K7)

Definition:
Current harmonic compensation represents one of the most salient storage features. The operation of PV inverters highly influences the current total harmonic distortion (THD) of transformers, mostly on power on and power off periods. By monitoring transformer loads, storage operation should compensate highly distorted currents during the most critical periods.

Local voltage harmonic distortion normally represents the sum of offset THD level influenced by the operation of middle voltage level and the influence of the local current on specific low voltage network impedance. Voltage THD improvement, therefore, depends only on the influence of local current THD improvement on the existing network impedance.

Calculation:

$$\Delta I\ THD\ (\%) = \frac{I\ THD_{Grid,Use\ Case} - I\ THD_{Grid,Base\ Case}}{I\ THD_{Grid,Base\ Case}} * 100\%$$

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$\Delta I\ THD\ (\%)$	I THD grid change
$I\ THD_{Grid,Use\ Case}$	I THD grid use case
$I\ THD_{Grid,Use\ Case}$	I THD grid base case

$$\Delta U\ THD\ (\%) = \frac{U\ THD_{Grid,Use\ Case} - U\ THD_{Grid,Base\ Case}}{U\ THD_{Grid,Base\ Case}} * 100\%$$

$\Delta U\ THD\ (\%)$	U THD grid change
$U\ THD_{Grid,Use\ Case}$	U THD grid use case
$U\ THD_{Grid,Use\ Case}$	U THD grid base case

Proposed time interval:
24 hours
7 days
30 days

The KPI for the proposed time intervals should be calculated for equal/comparable sun radiation conditions.

9.4.6 Voltage deviation change (K8)

The voltage level in the electricity network can deviate from its nominal value due to several reasons:

- A voltage drop is expected along the MV and LV feeder in the direction of the power flow, from the injection location towards the consumption location.
- In intervals with high demand, the voltage profile decrease is significant and in times of low demand, the voltage profile rises.
- Additional voltage profile rise occurs due to distributed RES generation units, connected and injecting power to the distribution grid.

As a result, the voltage profile is variable in different locations of the grid and in different times of the day.
The nominal value of the voltage for a grid section is the voltage level, which is set on the transformer secondary taps. Expressed in per unit system, it is nominally 1.p.u.. In high demand grids it can be set to a higher value (e.g. 1.05 p.u.) or is regulated with OLTC transformer where the voltage level is set by controlling the transformer taps.

Definition:
Voltage deviation is defined as a relative change of the measured voltage level compared to the nominal voltage value.

$$VD[\%] = \frac{V_{Measured} - V_n}{V_n} \cdot 100\%$$

$V_{Measured}$	Measured voltage level [p.u.]

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V_n	Nominal voltage level [p.u.]
VD	Voltage deviation factor [%]

Voltage deviation change due to storage unit implementation is defined as a relative change of the voltage deviation factor between the base case and the study case:

$$\Delta VD = VD_{Base\ Case} - VD_{Study\ Case}$$

When expressed in [%], it is expressed as:

$$\Delta VD[\%] = \frac{VD_{Base\ Case} - VD_{Study\ Case}}{VD_{Base\ Case}} \cdot 100\%$$

Proposed time interval:
24 hours

9.5 Device level KPIs for performance monitoring

9.5.1 Full cycle equivalents of storage (K9)

Definition:
Full cycle equivalents of storage are the number of the full discharge cycles a storage unit could perform if every cycle of operation includes a full discharge.

Calculation:

$$FCE = \frac{E_{Out}[kWh]}{E_{Cap,nom}[kWh]}$$

$E_{Cap,nom}[kWh]$	The nominal storage capacity of the asset [kWh],
$E_{Out}[kWh]$	Total amount of energy that was extracted from the storage asset during the test period [kWh].

The energy E_{Out} is the integral of the power output $P_{Out}(t)$ [kW] at each time instance t, or directly measured at the device as $E_{Out}[kWh]$. Storage capacity $E_{Cap,nom}[kWh]$ is provided by the manufacturer and is given in the documentation.

$$E_{Othe\ ut}[kWh] = \int \quad P_{Out}(t)dt$$

Alternatively, the discharging energy is measured:

$$E_{Out}[kWh] = \sum_{k=1}^{n} \quad E_{Out}(k)$$

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Proposed time interval:
24 hours
7 days
30 days

9.5.2 Storage Capacity Factor (K10)

Definition:
Storage capacity factor SCF is defined as the ratio of maximum available capacity compared to the nominal storage capacity.

Calculation:

$$SCF(\%) = \frac{E_{Cap,measured}[kWh]}{E_{Cap,nom}[kWh]} \cdot 100\%$$

$E_{cap,measured}[kWh]$ This refers to the measured value of maximum storage capacity and degradation over time. It is measured once in a specified time interval (e.g. 6 months), by initiating a full charging and discharging cycle if control allows it, under operating conditions (e.g. temperature, power for charging and for discharging). If the storage operation within this interval reaches a state of full charge, the measurement should be saved for that instance as well, since it will help define the degradation curve more accurately.

$E_{Cap,nom}[kWh]$ Storage nominal capacity is provided by the manufacturer and is given in documentation [kWh].

Proposed time interval:
90 days
180 days

9.5.3 Storage efficiency (K11)

Definition:
Storage efficiency is defined as the overall system efficiency, comparing the amount of stored energy and energy injected from the device at the PCC back to the network.

Calculation:

$$\varepsilon_{Storage} = \frac{W_{in}}{W_{out}} * 100\%$$

$\varepsilon_{Storage}[\%]$	Storage efficiency [%]
W_{in}	Energy stored in the device [kWh]
W_{out}	Energy extracted from the device [kWh]

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Proposed time interval:
7 days
30 days

In the case of CAES the storage efficiency o can best be described as the 'Return Trip Electrical Efficiency'. This is the ratio of the electrical energy exported during expansion compared to the electricity imported during compression. Commercial CAES systems need to achieve a RTEE of between 60% and 75% in order to be considered viable. Most of the system energy losses are through heat loss to atmosphere. The design aim of an isothermal CAES system is to limit process air temperature rise through high performance internal heat exchange which in turn reduces the heat transfer temperature gradient to ambient. A project specific KPI in respect of heat exchanger thermodynamic performance can therefore be described as the 'process air temperature rise at full power condition'. Note, This KPI value can be measured in compression mode and assumed to be the same value for temperature drop in expansion mode.

9.5.4 Device availability (storage or other technical solution) (K12)

Definition:
The reliability of the operating devices needs to be monitored. Device availability is defined as a comparison of the time, or the number of availability checks, when the device is available for operation and the duration of the monitored interval. The fallout duration is determined by measuring the time between the availability checks.

Calculation:

$$DA = (1 - \frac{\sum_{t=1}^{N} \quad D_{NA}}{\sum_{t=1}^{N} \quad D_{A}}) * 100\%$$

$$DA = (1 - \frac{\sum_{t=1}^{N} \quad D_{NA}}{N}) * 100\%$$

DA	Device availability (%)
D_{NA}	Device not available check (integer/counter)
N	Number of time instances / number of availability checks (integer/counter)

Proposed time interval: 1 year

In case of the CAES availability is determined with application of same formula both for generators, storage units or any other device, or overall performance of a facility, if needed. Availability is the proportion of time that a device or system is in a functioning condition. It is calculated using the following formula:

$$Availability(\%) = \left(\frac{MTTF(h)}{MTTF(h) + MTTR(h)} \right) \cdot 100$$

MTTF = Mean time to failure in hours

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$MTTR$ = Mean time to repair in hours

9.6 Economic KPIs

9.6.1 Change of revenue for the main actors (K13)

Definition:
Change of revenue for the main actors (end consumer, PV owner, DSO, Storage owner) are defined as the difference between existing revenues and revenues after upgrading the system (storage implementation, PV installation or smart inverter upgrade, etc.). For the end consumer, for example, the energy costs may be lower (costs savings) or new market revenues may be included.

By generalizing the $R_{current}$ and R_{new} on monthly or yearly expenses/revenue changes, the problems of missing data and unnecessary details regarding different electricity prices, network costs and missing measurements are avoided. For each demo case, the basic economic differences are calculated, and by their comparison, broad explanations can be given of the differences that occur due to the different business models, electricity price, etc.

Calculation:

$$\Delta P_{Revenue} = R_{Current} - R_{New}$$

$\Delta P_{Revenue}$	Change of revenue [€]
$R_{Current}$	Current, existing revenue (Base Case)[€]
R_{New}	New revenues (Demo) [€]

Proposed time interval:
30 days
1 Year

9.6.2 Average cost of energy consumption (K14)

This KPI evaluates the cost decrease that can be achieved through demand response. The average cost of energy consumption is calculated before and after the storage implementation with the following formula:

Calculation:

$$\emptyset E, cost = \frac{E, cost}{E, consumption}$$

$\emptyset E, cost$	Average cost of energy consumption [€/kWh]
$E, cost$	Cost of energy consumption [€]
$E, consumption$	Total energy consumption [kWh]

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9.7 Environmental KPIs

9.7.1 Change of emissions (K15)

Definition:
This KPI has been selected to evaluate the benefits associated with environmental sustainability. The greenhouse gas (GHG) emissions reduction per year and per kWh in % due to the increase of the renewables contribution to the energy supply in the network is calculated. The Base Case (BC) corresponds to an emissions rate before implementation of the storage, which is compared to the emissions rate of the specific case study (CS).

Calculation:

$$\Delta CO_2 eq(\%) = \frac{CO_{2eq,BC} - CO_{2eq,CS}}{CO_{2eq,BC}} \cdot 100$$

CO_{2eq} describes the global warming potential on a 100 year basis (GWP 100). For its calculation the GHG emissions CO_2, CH_4, and N_2O are included with a life-cycle assessment. In demonstrations using heat pumps FKW, FCKW, HFCKW or CKW emissions are also considered. Besides GHG emissions the reduction of air pollutants (e.g. SO_2, NO_x, NH_3, CO, NMVOC, fine particles) are calculated with the same method.

$CO_{2,CS}$ is calculated with the following formula:

Calculations:

$$CO_{2,CS} = \frac{CO_2[g/kWh, grid] \cdot E_{grid}[kWh]}{E_{Loads}[kWh]}$$

$$\begin{aligned} CO2eq, CS = & [g\ CO2eq\ /\ kWh\ grid\ electricity]\ x\ kWh\ grid\ electricity \\ & + [g\ CO2eq\ /\ kWh\ PV\ electricity]\ x\ kWh\ PV\ electricity \\ & + [g\ CO2eq\ /\ kWh\ battery]\ x\ kWh\ electricity\ out\ of\ battery \end{aligned}$$

Proposed time interval:
Seasonal.

9.7.2 Avoided emission cost (K16)

Definition:
Based on the reduced emissions due to a higher share of renewables, the KPI avoided emission cost (CO_2, CH_4 and N_2O) is calculated in €.

Calculation:

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$$CA = \sum_{i=1}^{N} EQ_i * EC_i$$

CA	avoided cost [€]
N	number of GHG emissions
EQ_i	*i*-th emission quantity [t]
EC_i	*i*-the emission cost [€/t]

No primary data are needed, all data results from the LCA.

Proposed time interval:
Annual
Seasonal

10 Demo specific technical KPIs

This chapter describes the demo specific KPI's, which are assessed in addition to the general KPI's.

10.1 Oud –Heverlee buildings

10.1.1 Generation and consumption prediction accuracy (K17)

Two prediction models are used to forecast the net consumption $C_{tot}(t)$ and generation $G_{tot}(t)$ at any time t during the experimentation period Ω. The accuracy of both models is evaluated respectively through the computation of their root-mean-square error e^{c}_{rms} & e^{g}_{rms} .

$$e^{c}_{rms} = \left(\sum_{t \in \Omega} \left(C_{tot}(t) - \hat{C}_{tot}(tot) \right)^2 \right)^{\frac{1}{2}}$$

$$e^{g}_{rms} = \left(\sum_{t \in \Omega} \left(G_{tot}(t) - G_{tot}(tot) \right)^2 \right)^{\frac{1}{2}}$$

In case large shares of the consumption/generation are actively managed, and that activation times (for both consumption/generation directions) can be freely decided by the operator, the prediction of the total consumption and generation can be useless. Indeed, it is better to predict the uncontrollable part of consumption/generation in this case.

10.1.2 (In)voluntary imbalance (K18)

The voluntary and involuntary imbalance volumes should be assessed as boxplots, and relatively to two axes: the amount delivered and the amount required. The delivered kW corresponds to the difference between the metered consumption/generation with its forecast

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value during the activation. The expected kW is the amount of kW expected to be delivered during each activation.

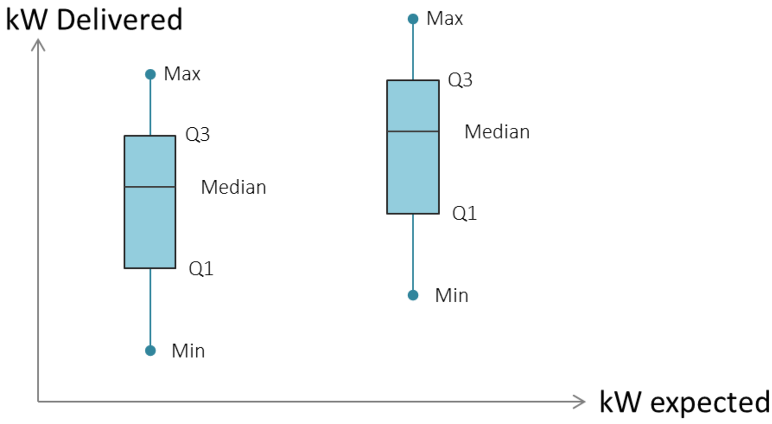

Figure 2: (In)voluntary imbalance

10.1.3 Available flexible power & energy (K19)

For each flexible element, the average available flexible power and energy should be assessed for each 4-hour period of the day in the following periods.

- Winter Weekday [0h-4h]; [4h-8h] ; [8h-12h] ; [12h-16h]; [16h-20h],[20h-24h]
- Winter Weekend - idem
- Summer Weekday - idem
- Summer Weekend - idem

The available flexibility is defined by reference of a generation asset: if the local generation can be increased or that the local consumption can be decreased, we talk about an upward (positive) flexibility, and inversely for downward (negative) flexibility.

The available flexible power must, in addition, be segmented by the amount of time during which it can be delivered. We propose the following *duration of delivery* (DuDe) segmentation.

- Flexible Power available during 15 minutes
- " " " " 30 minutes
- " " " " 1 hour
- " " " " 2 hours
- " " " " 4 hours

Therefore, there will be 2 (up/downward) $\times 4 \times 4$ (typical day type) $\times 5 \times 5$ (Duration of delivery) tables of 6 entries (hour interval).

For a defined

- 4-hour period of the day: k
- Typical day type (Winter/summer & Weekday/Weekend): d
- Direction upward/Downward flexible power: up or dn
- And asset i (household, generator, battery).
- Duration of delivery DuDe (15',30',1h, 2h,4h)

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We define the quantity $FP_{i,k,d}^{up}(DuDe)$, where TTC (time to charge), TTD (time to discharge) and P_i are defined below.

$$FP_{i,k,d}^{up}(DuDe) = P_{i,k,d}^{up} \cdot \frac{TTD_{i,k,d}}{DuDe}$$
$$FP_{i,k,d}^{dn}(DuDe) = P_{i,k,d}^{dn} \cdot \frac{TTC_{i,k,d}}{DuDe}$$

And the sum over all flexible assets:

$$FP_{tot,k,d}^{up}(DuDe) = \sum_i FP_{i,k,d}^{up}(DuDe)$$
$$FP_{tot,k,d}^{dn}(DuDe) = \sum_i FP_{i,k,d}^{dn}(DuDe)$$

That is based on the **average** upward available power $P_{i,k,d}^{up}$ and downward available power $P_{i,k,d}^{dn}$ of each asset i computed over all $N_{k,d}$ time steps (measurements) within period k of all days of typical type d. This is defined differently for the generation units or consumption appliances or storage asset. For storage asset, we distinguish charging and discharging modes.
Generation unit upward (except for PV where this is always zero):

$$P_{i,k,d}^{up} = P_i^{nom} - \frac{1}{N_{k,d}} \sum_{t \in k\&d} P_i(t)$$

Consumption appliance upward:

$$P_{i,k,d}^{up} = -\frac{1}{N_{k,d}} \sum_{t \in k\&d} P_i(t)$$

Storage asset upward

$$P_{i,k,d}^{up} = P_i^{nom,\text{discharge}} - \frac{1}{N_{k,d}} \sum_{t \in k\&d} P_i^{\text{discharge}}(t)$$

Generation unit downward

$$P_{i,k,d}^{dn} = P_i^{nom} - \frac{1}{N_{k,d}} \sum_{t \in k\&d} P_i(t)$$

Consumption appliance downward

$$P_{i,k,d}^{up} = P_i^{nom} - \frac{1}{N_{k,d}} \sum_{t \in k\&d} P_i(t)$$

Storage asset downward

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$$P_{i,k,d}^{dn} = P_i^{nom,\mathrm{charge}} - \frac{1}{N_{k,d}} \sum_{t \in k \& d} P_i^{\mathrm{charge}}(t)$$

where P_i^{nom} is the nominal power of asset i (>0 if generation, <0 if consumption), and time t is any time step of duration Δt within period k of day d (that counts in total $N_{k,d}$ of such time steps) and $P_i(t)$ corresponds to the net power generation of asset i (>0 if produced, <0 if consumed) over the same time step t.

Energy limits are grasped by the concept of average time to charge (TTC) and average time to discharge (TTD) of asset i, also computed over all time steps t within each hourly period k in the days corresponding to the typical day d.

TTC is the average time needed to be fully charged if the storage asset, consumption appliance was running at nominal power. TTD is the same concept for discharging time.

10.1.4 ICT gateway availability and volumes (K20)

The ICT Gateway availability is estimated by the time during which it could be accessed by the different connected assets.
For each asset and time t during the experimentation period Ω, the availability of the gateway $GateAv_i(t)$ is 1 in case the asset could have sent information to the gateway and zero otherwise.
The overall ICT gateway availability is (there are N_i assets and N_t measurement intervals).

$$GateAv_{tot} = \frac{1}{N_i \cdot N_t} \sum_{i,t \in \Omega} GateAv_i(t)$$

The data exchanged volumes are the sum of all exchanged data during the experimentation. Additionally, the number of connected devices N_{dev} is derived from $GateAv_{tot}$.

$$N_{dev} = N_i \cdot GateAv_{tot}$$

10.1.5 Consumption change (K21)

It is important to monitor the evolution of total electric consumption as a consequence of the optimization. Indeed, due to storage losses, it may very well be that the consumption will increase, except in case the initial control algorithm (e.g., local thermostat) was leading to unnecessary consumption.

Using the concept of the reference consumption, the relative consumption at time t is

$$\frac{C_i(t) - \left(C_{i,u}(t) + \hat{C}_{i,c}^0(t)\right)}{\left(C_{i,u}(t) + \hat{C}_{i,c}^0(t)\right)}$$

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10.2 Lecale

10.2.1 Demand side reduction (K22)

When CAES is compressing and therefore acting as a load on the system we become eligible for demand side reduction services that would be described in a service contract with a Demand Side Unit (DSU). In the event of a system requirement the trip signal to shut down the compressor comes from DSU and payment in respect of contract is triggered.
The KPI will be measured by technical performance of the CAES control system to switch off when called to do so in compliance with the DSU requirements and by fulfilment of all of the commercial agreements i.e. Demand Side Reduction Agreement with DSU.
KPI:

$$\mathrm{Re}\,liability(\%) = \frac{MTBF(h)}{MTBF(h) + MTTR(H)} \cdot 100$$

MTBF	= Mean time between failures
MTTR	= Mean time to repair

10.2.2 Standby generation (K23)

The KPI will be measured by the technical performance of the CAES control system to start expansion when called to do so in compliance with the System Operator Northern Ireland (SONI) requirements and by fulfilment of the commercial contract i.e. Capacity Agreement.
KPI:

$$\mathrm{Re}\,liability(\%) = \frac{MTBF(h)}{MTBF(h) + MTTR(H)} \cdot 100$$

MTBF	= Mean time between failures
MTTR	= Mean time to repair

10.2.3 Peak lopping (K24)

KPI: (E/P ratio increase)

$$\Delta P(\%) = \frac{P_{CS}[kW] - P_{BC}[kW]}{P_{BC}[kW]} \cdot 100$$

$\Delta P(\%)$	relative average peak power change
P_{CS}	is grid peak average power in Case Study
P_{BC}	is grid peak average power in Base Case

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10.2.4 Generation on demand (K25)

KPI:

$$\mathrm{Re}\,liability(\%) = \frac{MTBF(h)}{MTBF(h) + MTTR(H)} \cdot 100$$

MTBF = Mean time between failures
MTTR = Mean time to repair

10.2.5 Augmenting DNO managed connections (K26)

- PR gain for NIE (DNO) (Yes/No statement)
- More cost effective grid connections for generators (Yes/No statement)
- More efficient use of renewable generators leading to reduced fossil emissions (Emissions reduction KPI)

10.2.6 Load on demand (K27)

KPI:

$$\mathrm{Re}\,liability(\%) = \frac{MTBF(h)}{MTBF(h) + MTTR(H)} \cdot 100$$

MTBF = Mean time between failures
MTTR = Mean time to repair

10.3 Demos Beneens

10.3.1 Electrical performance of the ORC (K28)

In order to get a profitable business case for the ORC, it is important to maximize electricity production. By integrating thermal energy storage, part of the heat demand peaks is fulfilled with heat from this storage, allowing part of the produced heat to be redirected to the ORC simultaneously and thus increases the yearly electrical power production of the ORC.
Two related KPI's are defined:

10.3.2 ORC Utilization Rate (K29)

Yearly electricity production of the ORC with thermal energy storage over the maximum technical potential of electricity production in a year:

$$E_{utilization}[\%] = \frac{E_{ORC,electrical}\,[{}^{kWh}/_{year}]}{E_{ORC,theoretical}\,[{}^{kWh}/_{year}]}$$

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Here, $E_{ORC,electrical}$ is the amount of electricity produced by the ORC during the monitoring period, which is measured.

$E_{ORC,theoretical}$ is calculated by counting all hours the boiler was operational multiplied by the nominal thermal input power of the ORC and ORC efficiency.

10.3.3 Storage ORC efficiency (K30)

This KPI indicates the relative amount of additional electricity produced due to the integration of storage.
Definition: Difference between yearly electricity production of the ORC with thermal energy storage and the yearly electricity production of the ORC without thermal energy storage, over the yearly electricity production of the ORC without thermal energy storage.

$$E_{storage}[\%] = \left[\frac{E_{ORC,electrical}\,[{}^{kWh}/_{year}] - E_{ORC,electrical,no\ storage}\,[{}^{kWh}/_{year}]}{E_{ORC,electrical,no\ storage}\,[{}^{kWh}/_{year}]}\right].100$$

$E_{ORC,electrical}$ is the amount of electricity produced by the system as measured. The value for $E_{ORC,electrical,no\ storage}$ is theoretical and is calculated by considering the times when the boiler runs at full load and heat is directed from the high-temperature storage to the processes, simultaneously. The amount of heat that is delivered to the ORC should be reduced by the amount of heat that flows from the high-temperature storage and the reduction in electricity produced by the ORC is calculated:

$$\begin{aligned} P_{ORC,electrical,no\ storage} &= P_{ORC,electrical,storage}\ \ if\ P_{high\ T\ storage\rightarrow DHN} \leq 0 \\ &= \ (P_{ORC,thermal,storage} - \ P_{high\ T\ storage\rightarrow DHN})\varepsilon_{ORC}\ if\ P_{high\ T\ storage\rightarrow DHN} > 0 \end{aligned}$$

With ε_{ORC} the ORC efficiency.

10.3.4 Share of covered thermal demand (K31)

The thermal power of the biomass boiler is lower than the sum of the power of all heat consumers connected to the installation. The ORC's electric power production has to be reduced or even switched off during periods of high total heat demand.

In order to reduce the net heat demand, thermal energy storage tanks have been placed in both the high temperature (50 m³ water storage) and the low temperature circuit (20 m³ water storage). By intelligent control of the loading/unloading process of the storage tanks, the heat demand peaks can be (partly) met by the heat stored in the storage tanks resulting in a higher electricity production of the ORC.

Two related KPI's can be defined.

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10.3.5 Heat fulfilment share (K32)

Time over the year that all the heat demand can be fulfilled over the time over the year with heat demand.

$$T_{fulfilled}[\%] = \frac{t_{demand,covered}\ [^{h}/_{year}]}{t_{demand,total}\,[^{h}/_{year}]} = \frac{t_{demand,total}\,[^{h}/_{year}] - t_{demand,not\ covered}\,[^{h}/_{year}]}{t_{demand,total}\,[^{h}/_{year}]}.100$$

$t_{demand,total}$ is obtained by counting all hours when heat required by any process, including the ORC. $t_{demand,covered}$ is calculated as the difference between the total time with heat demand and the time when the heat demand is not fully covered, $t_{demand,not\ covered}$. It is assumed that the heat demand is not fully covered when :

- The boiler is delivering thermal energy at full power;
- The State-of-charge of the thermal energy storage units is 0

The combination of these conditions ensures that all energy produced by the boiler is directed to the processes directly and thereby it is assumed that the demand exceeds the production capabilities.

10.3.6 Storage-related coverage increase (K33)

This KPI estimates how the share of thermal demand coverage defined previously is increased by the addition of storage.

$$T_{fulfilled,storage}[\%] = \frac{t_{demand,covered}\,[^{h}/_{year}] - t_{demand,covered,no\ storage}\,[^{h}/_{year}]}{t_{demand,covered,no\ storage}\,[^{h}/_{year}]}.100$$

$t_{demand,covered}$ is the same value as defined in 1.2.1. The value for $t_{demand,covered,no\ storage}\,[^{h}/_{year}]$ can be calculated by summing the times when the total power of the processes exceeds the maximum power output of the boiler.

10.3.7 Additional overall thermal storage losses (K34)

The additional overal thermal storage losses will be calculated by integrating the net power flow to and from the storage and correcting for the potential energy content difference between the beginning and the end of the monitoring period.

$$E_{losses} = \int_{year} P_{primary\to storage} - P_{storage\to DHN}\, dt - \Delta E_{storage}$$

$P_{primary\to storage}$ and $P_{storage\to DHN}$ are the power flows to and from the storage, respectively. $\Delta E_{storage}$ is used to correct for the difference between the initial and the final energy content of

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the storage. In essence: the difference between the total energy injected and extracted is lost during the year (after correcting for the final state).

10.3.8 Heat loss reduction of district heating network by multi-temperature network (K35)

The new office building of Beneens is connected to the heating supply system and can be heated using the high temperature or the low temperature circuit. High temperature heating is needed for:

- Periods with high heating demand (cold winter days)
- Loading hot tap water of the storage tank

Reducing the supply temperature in the distribution pipes and the local distribution installation leads to lower heat losses from the pipes.

This KPI reflects the yearly decrease in distribution losses due to the use of a combined, high and low supply temperature in the distribution network compared to the use of only high supply temperature in the distribution network.

$$E_{losses,dist}\,[\%] = \frac{E_{losses,dist,high}\,[{}^{kWh}/_{year}] - E_{losses,dist,high+low}\,[{}^{kWh}/_{year}]}{E_{losses,dist,high}\,[{}^{kWh}/_{year}]}.100$$

$E_{losses,dist,x}$ losses is calculated using

$$E_{losses,dist,x} = \int_{year} Q_{losses}\,dt$$

where t is the duration of heating and Q_{losses} is the heat lost from the pipes:

$$Q_{losses} = 2.\pi.L.\frac{T_{in} - T_{out}}{\ln\frac{r_{out}}{r_{in}}.\frac{1}{k_{pipe}} + \ln\frac{r_{ins}}{r_{out}}.\frac{1}{k_{ins}}}$$

where k_{pipe} is the thermal conductivity of the pipe material, k_{ins} is the thermal conductivity of the insulation, T_{in} the inside temperature of the pipe, T_{out} the temperature around the insulated pipe, L the length of pipe, r_{in} the inner radius of the pipe, r_{out} outer radius of the pipe, and $r_{ins}$is the outside radius of the insulation.

10.4 Demos in Slovenia

10.4.1 Reactive Power Compensation Efficiency (K36)

Definition:

Reactive Power Compensation Efficiency presents the effectiveness and share of reactive power provided locally by the storage unit. It is defined as the ratio between locally provided

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reactive power and grid injected reactive power. This KPI is a direct indicator of the success of a reactive power compensation control, performed by local storage.

Calculation:

$$\varepsilon_Q = \frac{|Q_{storage}|}{|Q_{storage}|+|Q_{grid}|} \cdot 100\%$$

ε_Q Level of locally provided reactive power or efficiency of reactive power compensation
$Q_{storage}$ Reactive power, provided by storage unit [kVar] and
Q_{grid} Reactive power, supplied from grid [kVar].

Proposed time interval:
24 hours
7 days
30 days

11 Annex: Overview of all KPIs used per demo

Demo 1: OH LL and buildings	Increased RES use (K1), Increased self-consumption (K2), Change of peak-to-average demand ratio (K3Change of peak-to-average demand ratio (K3), Storage efficiency (K11), Device availability (storage or other technical solution) (K12), Change of revenue for the main actors (K13), Average cost of energy consumption (K14), Change of emissions (K15), Avoided emission cost (K16), Generation and consumption prediction accuracy (K17), (In)voluntary imbalance (K18), Available flexible power & energy (K19), ICT gateway availability and volumes (K20), Consumption change (K21)
Demo 2: OH LEC and flexible neighbourhood	Increased RES use (K1), Increased self-consumption (K2), Grid energy consumption change (K6), Current and voltage total harmonic distortion change (K7), Change of revenue for the main actors (K13), Average cost of energy consumption (K14), Change of emissions (K15), Avoided emission cost (K16), Generation and consumption prediction accuracy (K17), (In)voluntary imbalance (K18), Available flexible power & energy (K19), ICT gateway availability and volumes (K20), Consumption change (K21)Current and voltage total harmonic distortion change (K7)
Demo3: EXCAL	Increased RES use (K1), Increased self-consumption (K2), Change of peak-to-average demand ratio (K3), Relative peak power change (K4), Grid energy consumption change (K6), Full cycle equivalents of storage (K9), Storage Capacity Factor (K10), Storage efficiency (K11), Device availability (storage or other technical solution) (K12), Change of revenue for the main actors (K13), Average cost of energy consumption (K14), Change of emissions (K15), Avoided emission cost (K16)
Demo 4: BENEENS	Increased RES use (K1), Increased self-consumption (K2), Relative peak power change (K4), Change of revenue for the main actors (K13), Average cost of energy consumption (K14), Change of emissions (K15), Avoided emission cost (K16), Electrical performance of the ORC (K28), ORC Utilization Rate (K29), Storage ORC efficiency (K30), Share of covered thermal demand (K31), Heat fulfilment share (K32), Storage-related coverage increase (K33), Additional overall thermal storage losses (K34), Heat loss reduction of district heating network by multi-temperature network (K35)
Demo5:	Increased RES use (K1), Increased self-consumption (K2), Change of peak-to-average

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LECALE	demand ratio (K3), Relative peak power change (K4), Grid energy consumption change (K6), Current and voltage total harmonic distortion change (K7), Storage efficiency (K11), Device availability (storage or other technical solution) (K12), Change of revenue for the main actors (K13), Average cost of energy consumption (K14), Change of emissions (K15), Avoided emission cost (K16), Demand side reduction (K22), Standby generation (K23), Peak lopping (K24), Generation on demand (K25), Augmenting DNO managed connections (K26), Load on demand (K27)
Demo 6: Slovenian cases	Increased RES use (K1), Increased self-consumption (K2), Change of peak-to-average demand ratio (K3), Relative peak power change (K4), Grid energy consumption change (K6), Current and voltage total harmonic distortion change (K7), Storage efficiency (K11), Device availability (storage or other technical solution) (K12), Change of revenue for the main actors (K13), Average cost of energy consumption (K14), Change of emissions (K15), Avoided emission cost (K16), Reactive Power Compensation Efficiency (K36)

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